

# Analysis of the Disturbance Characteristics for Main Roof Fracturation on Anchoring Structure of Anchor Rod

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## Abstract

With the increase of mining intensity, mining pressure caused by coal mining presents complexity and diversity, especially that its performance of the strong dynamic load brings unpredictability to anchoring instability of mining roadway anchorage structure. This article studies the load disturbance time and disturbance characteristics before and after the main roof fractures through the analysis on the movement process of the hard brittle fault block from the main roof. And then, based on the numerical simulation, the adaptability characteristics of anchorage structure under strong dynamic load are studied, and the basic principles for anchoring parameters selection are put forward. The results show that the corresponding optimization design of anchoring parameters should be based on the layered characteristics of roadway surrounding rock and disturbing load characteristics.

## Keywords

Main Roof Fracturation, Disturbing Load, Anchorage Structure, Disturbance Adaptability

## Introduction

In recent years, with the innovation and development of the mining process, mining strength and advancing speed of working face has increased rapidly, for which major peculiar phenomena that the mining dynamic loses stability often happen. The phenomena are greatly characterized by suddenness and polytrope. Thus, experts and scholars have done a lot of fruitful work on the coal and rock dynamic phenomenon. Still, further research should be done on the impact of these phenomena on roadway supporting structure.

## Disturbance Analysis of Main Roof Fracturation

### Analysis on the Disturbing Load of Main Roof Fracturation

A certain thickness of the upper and lower layer of the

main roof is respectively regarded as elastic mediums which approximately match with the assumption of the Winkler elastic foundation, that is

$$p = -ky \quad (1)$$

Where  $p$ --perturbation pressure on the main roof caused by mining;  $y$ --vertical displacement of main roof;  $k$  is Winkler foundation coefficient related to the thickness and mechanical properties of the upper and lower clamped soft rock (immediate roof, coal seam and floor under main roof). According to the definition of the foundation coefficient, Qian Minggao etc. held that  $k$  is related to the thickness and mechanical properties of the cushion under the beam; additionally, the study of Qu chengzhong etc. showed the calculated formula of foundation modulus for hard soil or rock. Based on the analysis above, this article values Winkler foundation coefficient as

$$k = \eta_1 \cdot \frac{E_0}{H(1-\mu^2)} \cdot \left( \frac{12E_0}{Eh^2} \right)^{\eta_2} \quad (2)$$

Where  $E_0$ --soft rock's integrated elastic modulus of immediate roof, seam and floor below the main roof;  $H$ --soft rock thickness of immediate roof, seam and floor soft rock below the main roof;  $\mu$ --poison ratio;  $E$ --elastic modulus of main roof;  $h$ --main roof thickness;  $\eta_1, \eta_2$ --coefficient.

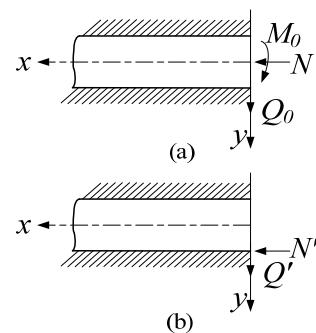


FIG.1 THE MECHANICAL MODEL OF MAIN ROOF BEFORE AND AFTER BREAKING

Assuming main roof breaks at coal wall ( $x=0$ ), as shown in Fig.1,  $M_0$ ,  $Q_0$ ,  $N$  are the beam cross-section internal forces corresponding to the mining face of the coal wall.

As we take fault blocks after main roof breaks with equal length (length- $L$ ), the sinkage of midpoint hinge of the three-hinged arch after breaking as  $h/6$ , the hanged length over mining field before main roof breaks as  $L'$ , the volume force of stratum as  $\gamma$ , the thickness of overlying load stratum on main roof as  $\Delta h$ , and considering that little effect will be made by support on the main roof stratum when it controls the immediate roof (mainly due to the impact of coal wall support on the angle), the supporting impact can be neglected. The result of the analysis on the "voussoir beam" three hinged-arch structure shows that  $M_0$ ,  $Q_0$ ,  $N$  are [9]

$$M_0 = \frac{1}{10} \gamma (h + \Delta h) L^2 + \gamma (h + \Delta h) L \cdot L' \quad (3)$$

$$Q_0 = \gamma (h + \Delta h) L' + \gamma (h + \Delta h) L \quad (4)$$

$$Q' = \gamma (h + \Delta h) L \quad (5)$$

$$N = N' = \frac{3\gamma (h + \Delta h)}{5h} L^2 \quad (6)$$

Set  $r^2 = k/EI$ ,  $s = N/EI$ , where  $EI$  is the bending stiffness of main roof, then

$$\begin{cases} \alpha = (r/2 - s/4)^{1/2} \\ \beta = (r/2 + s/4)^{1/2} \end{cases} \quad (7)$$

The perturbation pressure and vertical displacement on underlying rock of main roof caused by main roof breaking are

$$Y = \frac{M_0 [\gamma + \omega^2 + 2\alpha(1 + s/r)\omega]^{1/2}}{EI r \beta} \quad (8)$$

$$p = -kY e^{-\alpha x} \cos(\beta x - \varphi) \quad (9)$$

$$\text{When } \tan \varphi = \frac{2r\alpha + s\omega}{2\beta(r + 2\alpha\omega)}, \omega = \frac{Q_0}{M_0}$$

#### Analysis on Movement Process of Main Roof Fault Block

For the brittle or highly brittle main roof stratum, the moment it breaks, leads to the release of its elastic deformation energy and acceleration of its rotating. The moment the main roof stratum breaks, the released elastic deformation energy  $W_t$  is:

$$W_t = \frac{1}{2} E \cdot \varepsilon_d^2 \quad (10)$$

Where  $E$ --elastic modulus of main roof stratum;  $\varepsilon_d$ --elastic deformation limit of main roof stratum before forced breaking.

From Formula 10, it can be concluded that the greater both the elastic deformation and elastic modulus of main roof stratum before breaking are, the larger the released elastic deformation energy of stratum for the breaking moment will be. For the highly brittle main roof, because the consumed energy when breaking is much smaller than its accumulated elastic energy before breaking, its moment is fast pressurization. That is, the fast pressurization fault block has initial kinetic energy  $W_t$ .

From the analysis of the mechanical model of main roof stratum before or after fracture, it can be concluded that the main roof stratum can be assumed to be "side of the elastic support, while a beam clamped" before fracture, and can be assumed to be "simply supported beam" after fracture and rotary. Under the same load condition, the reaction force of front pivot is distinctly different before or after fracture. That is, the time of dynamic disturbance is rotating time from main roof stratum broken to its contacting waste rock, which occurs at the broken position by the rapid rotating of main roof stratum before or after fracture.

When the main roof stratum rotates rapidly, the weight  $Q$  of main roof fault block and overlying soft rock will accelerate its rotating, but the rated sustaining resistance  $P_{re}$  of support will decelerate its rotating. If the horizontal thrust impact between blocks can be neglected, the movement time  $t$  of the main roof fault block is satisfied with Formula 11.

$$\varphi = \sqrt{\frac{3E}{M}} \cdot \frac{\varepsilon_d}{L} t + \frac{3QL - 6P_{re}L_z}{4ML^2} t^2 \quad (11)$$

Where  $\varphi$ --rotation angle of main roof fault block when pressurization rotation is completed;  $L_z$ --distance of support acting on the main roof;  $L$ --length of main roof fault block along advancing direction;  $Q$ --weight of main roof fault block and overlying soft rock;  $P_{re}$ --rated sustaining resistance of support;  $M$ --quantity of main roof fault block.

#### Case Study

A mine's mining depth is 330m, and the mining thickness of coal seam is 7.5 m, and immediate roof over the coal seam is fine sandstone about 8.5 m (elasticity modulus set as 30 GPa). Main roof over the immediate roof is sandy conglomerate about 2.5 m and its upper load stratum thickness is 21.5 m consisting of thin powder fine sandstone intercalated gouge and non-mining coal seam. And at the higher level is another 3.0 m or so sandy conglomerate and its upper load stratum is about 25 m. By field measurement, the

periodic weighting length of main roof is 18 m. The rock volume force is set as 25 kN/m<sup>3</sup> and Winkler foundation coefficient as 1 GPa/m (a value based both on documents 2 and 3). Thus, by formula 6 to formula 12, when the elastic modulus of main roof is 45 GPa, the perturbation pressure is shown in graph 2 and graph 3. Graph 2 shows the changing perturbation pressure produced by immediate roof at varied distance from the breaking position in the course of the breaking of the basic roof. Graph 3 shows the changing perturbation pressure (abutment pressure) on next position of main roof with varied length of flap top within a circle of periodic weighting.

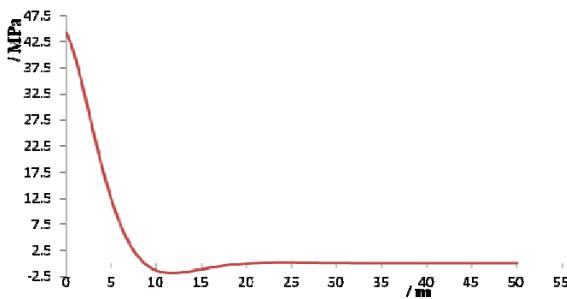


FIG. 2 THE PERTURBATION PRESSURE AT THE FRONT OF COAL WALL WHEN MAIN ROOF BREAKS

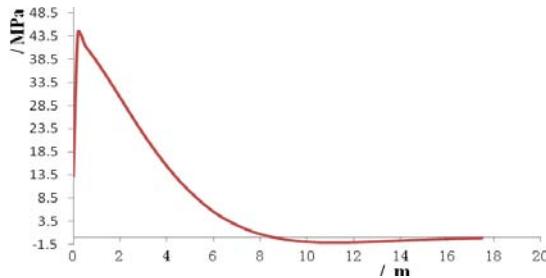


FIG. 3 ABUTMENT PRESSURE PRODUCED ON NEXT BREAKING POSITION BY FLAP TOP AFTER MAIN ROOF BREAKS

As it can be seen from Fig.2 and Fig.3 that the perturbation pressure when main roof breaks mainly acts on the front of breaking position within a smaller length (5 m); and at the breaking position the main roof produces step load, which changes in the range of about 3.3 times.

For a fully mechanized caving face, the machine mining thickness is 3.0 m, and the caving coal thickness is 4.5 m, and the mining ratio of top-coal is 0.8, and the immediate roof coefficient of bulk increase is 1.4, so the maximum subsidence of main roof stratum can be calculated as 3.2 m. That is, the rotation angle of main roof fault block from main roof stratum broken to its contacting waste rock is 10.1°. If we take the rated sustaining resistance of support as 7200 kN, and take the distance of support acting on the main roof as 6.5 m, and the elastic deformation limit of main

roof stratum as 0.20 m, the movement time  $t$  of the main roof fault block is calculated as 17.7 ms by Formula 11. If considering the perturbation pressure wave as half-sine kind (frequency  $f$  is  $t/2$ ), the disturbance wave frequency is 113 Hz, which belongs to seismic category, so the phenomena of stronger mine tremor often appear. In addition, due to the viscous effects of immediate roof and top coal, the responding frequency and energy of perturbation pressure wave of the basic roof will be significantly reduced on the coal wall of mining face and sectional level drift. The harder both immediate roof and top coal are, the higher both the responding frequency and energy on the coal wall of mining face and sectional level drift will be, and also the more obvious the disturbance is. When the immediate roof of the mine is fine-grained sandstone, and pu's hardness coefficient of the top coal  $f$  is 2.5~3, most energy of the perturbation pressure wave releases through free face of both the mining-face coal wall and sectional level drift, which is the reason for coal mass ejection at the fully mechanized mining-face coal wall.

#### Analysis on Dynamic Disturbance Adaptability of Anchorage Structure

##### *Numerical Simulation of Dynamic Response for Anchorage Structure*

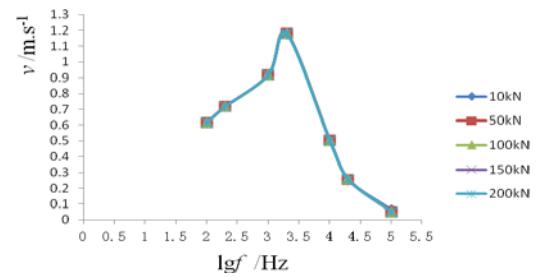


FIG. 4 VIBRATION VELOCITY AT THE EXPOSED END OF CABLE

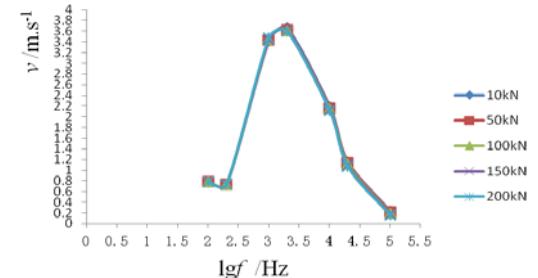


FIG. 5 VIBRATION VELOCITY AT THE INITIAL END OF ANCHORAGE

To explore adaptability of the pre-stressed anchor rod (cable) on dynamic disturbances such as mine tremor, FLAC3D is adopted to establish 2 m×2 m×6 m layered elastic rock mass (mechanical properties of layered

rock are separately set), and layer thickness is 0.5 m~1.0 m. The anchor cable and pallet are simulated by cable unit and shell unit, and the anchor cable length is set to be 6 m with anchoring length 1 m (bond strength 10 GPa), and pallet dimensions 0.3 m×0.3 m×0.1 m. The pre-stress of 10 kN, 50 kN, 100 kN, 150 kN and 200 kN are firstly applied in simulation, then the transient half-sine wave is normally applied at the rock mass end ( $x=6$  m) with a peak stress of 20 MPa. Under different pre-stress, the relation curve between node vibration velocity and excitation frequency is shown in Figure 4 and Figure 5 at the exposed end of anchor cable and initial end of anchorage structure.

It can be seen from Fig. 4 and Fig. 5 that for the pre-stressed rod (cable) in the complete and non-abscission rock, the pre-stress doesn't have significant effect on speed response acted on the perturbation pressure wave. With the increasing excitation frequency, the response value of cable speed at first increases and then decreases. In other word, there obviously has resonant frequency, which is much larger than the disturbance wave frequency 113 Hz. That is to say, the pre-stressed anchor rod (cable) has a high adaptability to the dynamic disturbances. Due to the differences in the mechanical properties of layered rock mass, vibration speed of adjacent nodes of cable differs greatly, and it is the stress wave reflection of layered rock interface (surrounding rock of cable not anchoring segment) that causes multiplied node vibration velocity of the initial end of anchorage structure.

#### *Analysis on Adaptability of Anchoring Parameters*

In summary, when breaking, brittle hard rock can produce low-frequency perturbation pressure waves under certain conditions (high-intensified mining and relatively complete hard immediate roof etc.). Most energy of the strong perturbation pressure wave releases through free face of mining-face coal wall and sectional level drift, which damages both the loading performance of anchorage structure and structure integrity of surrounding rock on roadway and mining face, and even causes ejection of coal rock mass or failure of the anchorage structure. In order to ensure the roadway surrounding rock stability under strong dynamic load, anchorage parameters such as the stiffness of support system, surface protecting component and pre-stress should adapt to the layered structure characteristics of surrounding rock and the disturbance load characteristics of brittle hard rock breaking. The specific measures are as follows:

(1) Through improving the support system stiffness of pre-stressed anchor rod (cable), its dynamic disturbance caused by main roof stratum breaking and its rotating can be reduced.

The system stiffness  $K$  of anchor rod (cable) can be divided into three parts in series which are pallet stiffness  $K_1$ , rod (cable) body stiffness  $K_2$  of non-anchor segment and anchorage body stiffness  $K_3$ . The system stiffness  $K$  of anchor rod (cable) is less than any of the three of  $K_1$ ,  $K_2$  and  $K_3$ . Generally,  $K_1$ ,  $K_2$  and  $K_3$  is in accord with both  $K_1 < K_3$  and  $K_2 < K_3$ , that is to say, the system stiffness  $K$  of anchor rod (cable) is determined by pallet stiffness  $K_1$  and rod (cable) body stiffness  $K_2$  of non-anchor segment. Because of the perturbation pressure waves being low-frequency when brittle hard rock fractures, and combined with aforementioned numerical simulation results, there does not produce resonance effect. But, we should raise anchor rod (cable) support system overall stiffness by increasing the stiffness of both pallet stiffness  $K_1$  and rod (cable) body stiffness  $K_2$ . We can raise  $K_1$  by increasing the thickness of pallet, and can raise  $K_2$  by increasing rod (cable) diameter and reducing non-anchor segment length.

(2) Superficial coal (rock) strata can be protected from spalling under the action of perturbation pressure through improving stiffness of surface protecting component and pre-stress of rod (cable).

Component protecting Surface mainly includes metal mesh and steel joists. If we take the steel joists as simply supported beam, whose beam length is larger than the spacing and row spacing of cable, the fundamental frequency of  $\phi 10$  mm steel joist is 150~200 Hz calculated by pure bending beam. Due to its fundamental frequency little different from the perturbation pressure wave frequency which is 113 Hz in the example calculation when brittle hard rock fractures, the resonant frequency is easily produced. At the same time, propagation of the perturbation pressure wave can produce reflection tension wave at the roadway surrounding rock wall, and easily cause surrounding rock spalling. In summary, the fundamental frequency of steel joist is ultimately improved by increasing pre-stress of anchor rod (cable) and diameter of steel joists, and reducing beam length of steel joists and slippage displacement between the plate and the surrounding rock wall. As in the above example mine, if the diameter of steel joists is increased from 10 mm to 14 mm, the deformation and destruction of superficial coal (rock) strata can be

greatly weakened.

(3) We should improve both the anti-strong dynamic load capacity and the whole and collaborative anti-distortion capacity by controlling the abscission between the layered rock-mass.

Determination of anchoring length of pre-stressed anchor rod (cable) is required not only to meet the anchoring loading requirements of surrounding rock, but also that the anchoring initiation position keeps a certain distance higher than the interface of main roof and immediate roof, which can avoid the multiplication of bond stress caused by the stress wave reflection in both sides of the interface. Determination of pre-stress of anchor rod (cable) is required to meet the purpose of preventing abscission between the layered rock-mass, so the value of pre-stress is determined by the curvature consistency of the upper and lower layers. Due to the great difference between the natural frequency of pre-stress anchoring system of anchor rod and cable, and in order to avoid single-destruction due to resonance effects, the combined usage of both and common loading should be achieved by measures such as truss.

## Conclusions

(1) The perturbation pressure when main roof breaks mainly acts on the front of breaking position within a smaller length. The closer the mechanical properties of immediate roof and main roof is, the smaller the rotated angle of main roof before breaking will be, the greater the elastic deformation of main roof stratum before breaking is, the shorter the action time of perturbation pressure wave will also be.

(2) The main roof produces step load when and after breaking at the breaking position, and the step load produced when breaking mainly acts on the front of breaking position within a smaller length, and the step load produces perturbation pressure wave on the elastic foundation of immediate roof.

(3) For the pre-stressed anchor rod (cable) in the complete and non-abscission layered rock, the pre-stress doesn't have significant effect on its speed response under the action of perturbation pressure wave, and the pre-stress mainly controls the abscission layer between layered rock-mass. There is no linear relationship between the excitation frequency of perturbation pressure wave and velocity response after the pressure acts but resonant frequency effect does exist.

(4) Because of different roadway conditions of

surrounding rock and characteristics of disturbance load, the dynamic responses of the pre-stress anchor rod (cable) are completely different under the condition of different anchoring parameters. So the optimization design of anchoring parameters should be based on its adaptability principles.

## ACKNOWLEDGMENTS

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